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(54) Title of the Invention

SINGLE MODE FIBER WITH BROAD WAVELENGTH RANGE AND LOW DISPERSION

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SPECIFICATIONS

1. Title of the Invention

Single Mode Fiber with Broad Wavelength Range and Low Dispersion

2. Claims

Single mode fiber with a broad wavelength range and low dispersion manufactured using the MCVD method characterized by the fact that in a single mode fiber with multiple structure refractive index distribution that has a multiplex structure which comprises the innermost layer (1), the second layer (2), the third layer (3) and the outermost layer (4) respectively from the inside in a concentric circular shape, each of whose refractive index varies in steps,
refractive index of the portion of the innermost layer (1) connected to the second layer (2) gradually decreases in the positive radial direction so as to connect itself to the second layer, while the difference between the refractive index of the portion with the maximum refractive index in the innermost layer (1) and the refractive index of the outermost layer (4) is between 1.0 % and 1.1 %.;
the refractive index of the second layer (2) is kept constant in the radial direction and the difference between that and the refractive index of the outermost layer (4) is between –0.3 % and –0.2 %;
the refractive index of the third layer (3) is kept constant in the radial direction and the difference between that and the refractive index of the outermost layer (4) is 0.2 % 0.02 %;
the refractive index of the outermost layer (4) is kept constant in the radial direction;
the radius of the innermost layer (1) is 3 ± 0.3 μm;
the proportion of the radius of the innermost layer (1) to that of the second layer (2) is 2.3 and;
the proportion of the radius of the innermost layer (1) to that of the third layer (3) is 3.

3. Detailed Description of the Invention

[Table of Contents]

[Introduction]

Single mode fiber multiple structured refractive index manufactured using the MCVD method which comprises the innermost layer which forms the core, the second layer, the third layer and the outermost layer which forms the cladding, respectively from the inside in a concentric circular shape, each of whose refractive index is varied in steps, while the refractive

index of the portion of the innermost layer connected to the second layer gradually decreases in the radial direction so as to connect itself to the second layer, and the refractive indices of the second and third layers as well as the outermost layer are kept constant. Furthermore, the difference between the refractive index of the portion with the maximum refractive index in the innermost layer and the refractive index of the outermost layer is a fixed positive value, and so is the difference between the refractive index of the third layer and that of the outermost layer, while the difference between the refractive index of the second layer and the outermost layer is a fixed negative value. The radius of the innermost layer is fixed, and the proportion of the radius of the innermost layer to that of the second layer as well as the proportion of the radius of the innermost layer to that of the third layer are fixed, thus reducing loss due to curving by preventing the basic mode from having a cut-off region.

Moreover, since the refractive index of the portion of the innermost layer connected to the second layer gradually decreases in the positive radial direction, fluctuation in the refractive index in the longitudinal direction of the optical fiber is made less likely to occur in this portion, and loss due to structure is reduced and worsening of wavelength dispersion is prevented.

[Technical Field of the Invention]

The present invention relates to a single mode fiber which has a broad wavelength range and low dispersion, especially to such single mode fiber which can be used in a wide enough wavelength range while the loss due to curving is small, and increased loss due to the incomplete structure of the fiber does not occur.

In optical transmission, it is necessary to be able to use a broad wavelength range. Single mode fibers with a broad wavelength range and low dispersion are being developed to suit this purpose, and such fibers which can be applied to wider wavelength range and small loss due to curving and which do not create increased loss due to incomplete structure are especially needed.

[Prior Art]

Conventionally, W-type single mode fibers have been proposed as single mode optical fibers with a broad wavelength range and low dispersion. Figure 9 shows a cross-section of such fiber, and here, the middle layer 13 with a refractive index of n_3 ($n_3<n_2$) between core 11 and cladding 12, when the refractive index of the core 11 is n_1 and that of the cladding 12 is n_2 ($n_1>n_2$). The characteristics of delay τ in this case are as shown in Figure 10 (a) based on differences between [illegible] refractive indices with respect to wavelengths of different layers. Specifically, characteristics A of the core 11, characteristics B of the cladding 12, and characteristics C of the middle layer 13 render the fiber characteristics D to be represented as a cubic curve. Here, E indicates characteristics of a conventional optical fiber for reference. F in Figure 10 (b) indicates that wavelength dispersion m shows the characteristics with which it becomes 0 in two different wavelengths, and accordingly, [the fiber in the present invention] has a lower dispersion in a broad wavelength range compared with conventional single mode fibers.

However, problems with W-type single mode fiber shown in Figure 9 include not only that the applicable range is not wide enough but also that the radiation loss when curved hinders its practical application.

The reason for this is considered to be that in the case of single mode fiber, there is a cut-off in the basic mode in the low wavelengths area shown as a dotted curve in the Figure 10 (a) delay characteristics, which does not allow transmission of light exceeding a certain wavelength, and this characteristic is further reinforced by curving.

To solve these problems, a single mode fiber with a broad wavelength range and low dispersion can be provided by giving it a four-layer structure as shown in Figure 11.

Specifically, a single mode fiber with a broad wavelength range and low dispersion which has a multi-layered structure is constructed with the innermost layer 21 which forms the core, the second layer 22, the third layer 23 and the outermost layer 24 which forms the cladding, placed respectively from the inside so that it has a concentric circular shape, and the refractive index of each part is varied in steps. The difference between the refractive index of the innermost layer 21 and that of the outermost layer 24 as well as the difference between the refractive index of the third layer 23 and that of the outermost layer 24 are fixed positive values, the difference between refractive index of the second layer 22 and that of the outermost layer 24 is a fixed positive value, when the diameter of the innermost layer 21 is also fixed. Furthermore, the proportion of the diameter of the innermost layer 21 to that of the second layer 22 and also the proportion of the diameter of the innermost layer 21 to that of the third layer 23 are fixed, and by giving appropriate values for the refractive index and diameter of each layer, it can be used in a broad wavelength range and loss due to curving can be reduced.

Figure 12 shows the characteristics of this fiber and the delay τ has such characteristics represented as a fourth order curve e in Figure 12 due to the characteristics a of the innermost layer 21, characteristics d of the second layer 22, characteristics c of the third layer 23, and characteristics d of the outermost layer 14 which forms the cladding. Thus, wavelength dispersion m increases toward the right-hand side as shown in Figure 12 (b). When this [fiber] is compared with W-type single mode fiber shown in Figure 9, it has smaller range where the dispersion becomes low, and its loss due to curving is reduced since [the basic mode] is prevented from having a cut-off region.

[Problems to Be Solved by the Invention]

It is desirable that the conventional single mode optical fiber with a low dispersion and broad wavelength range shown in Figure 11 have a high refractive index in the third layer 23 to ameliorate the functions. However, fluctuations are likely to occur in the longitudinal direction of the fiber in the refractive index of the portion of the innermost layer 21 connected to the second layer 22. Therefore, there have been problems such as low dispersion due to the existence of the layer 23 being reduced while light loss increases.

[Means Used to Solve the Abovementioned Problems]

Figure 1 shows the basic structure of this invention.

Single mode fiber with a broad wavelength range and low dispersion manufactured using the MCVD method has a multi-layered structure refractive index distribution and comprises the innermost layer 1 with refractive index n_1 and radius r_1, the second layer 2 with refractive index n_2 and radius r_2, the third layer 3 with refractive index n_3 and radius r_3 and the outermost layer 4 with refractive index n_4 and radius r_4, positioned respectively from the inside in a concentric circular shape, each of whose refractive index varies in steps.

Refractive index of the portion of the innermost layer 1 connected to the second layer 2 gradually decreases in the positive radial direction so as to connect itself to the second layer, while the refractive indices of the second layer 2, the third layer 3 and the fourth layer 4, i.e., n_2, n_3, n_4, are constant in the radial direction, and the difference Δ_1 between the refractive index of the portion with the maximum refractive index n_1 in the innermost layer 1 and the refractive index n_4 of the outermost layer 4 is between 1.0 % and 1.1 %;
the difference Δ_2 between the refractive index n_2 of the second layer 2 and the refractive index n_4 of the outermost layer 4 is between –0.3 % and –0.2 %;
the difference Δ_3 between the refractive index n_3 of the third layer 3 and the refractive index n_4 of the outermost layer 4 is 0.2 % ± 0.02 %;
the radius r_1 of the innermost layer 1 is 3 ± 0.3 µm;
the proportion of the radius r_1 of the innermost layer (1) to the radius r_2 of the second layer (2) is 2.3 and;
the proportion of the radius r_1 of the innermost layer (1) to the radius r_3 of the third layer (3) is 3.

[Operation of the Invention]

Figure 2 shows the delay characteristics (a) and the wavelength dispersion (b) of the single mode fiber with a broad wavelength range and low dispersion whose basic structure is shown in Figure 1. Specifically, as shown in (a), of the delay τ of the fiber has characteristics represented as a fourth order curve due to the characteristics a of the innermost layer 21, characteristics b of the second layer 22, characteristics c of the third layer 23, and characteristics d of the outermost layer 14 which forms the cladding, while wavelength dispersion m increases toward the right-hand side. This causes [the fiber] to have a smaller range where the dispersion becomes low, and its loss due to curving is reduced since [the basic mode] is prevented from having a cut-off region. Moreover, since the portion of the innermost layer 1 connected to the second layer 2 gradually decreases in the positive radial direction, fluctuation in refractive index in the longitudinal direction of the optical fiber is made less likely to occur in this portion, and loss due to incomplete structure at the time of production is reduced and worsening of wavelength dispersion is prevented.

[Embodiments]

(First Embodiment)

Figure 3 shows one embodiment of the present invention. The same keys are used for the same portions as in Figure 1.

As shown in Figure 3, the radius of each portion in this embodiment is:
r_1 = 3 µm
r_2 = 6.9 µm
r_3 = 9.1 µm
r_4 = Cladding radius.

Further, based on the refractive index n_4 (quartz), each refractive index difference is:
Δ_1 = 1.05 %
Δ_2 = -0.3%
Δ_3 = 0.19%.

The main elements in this case are as shown in Table 1.

Cut-off wavelength	1.17 μm
Mode field diameter	5.6 μm (1.3 μm) 7.1 μm (1.55μm)
Loss due to curving)	0.12dB/m (1.55μm)
Light loss	0.57 dB/km (1.3 μm) 0.27 dB/km (1.55μm)

Cut-off wavelength
Mode field diameter
Loss due to curving
Light loss

One example of wavelength dispersion of a single mode fiber with a broad wavelength range and low dispersion in this embodiment is as shown in Figure 4. It is considerably better than the dispersion shown by conventional single mode fibers or W-type single mode fibers.

(Second Embodiment)

Figure 5 shows another embodiment of the present invention, which concerns 1.55 μm band. The same keys are used for the same portions as in Figure 1.

This embodiment shows a case in which the dimension and refractive index of each layer are varied using three different values as shown in Figure 5. When each value is indicated as either (1): thick solid line / curve, (2): dotted line / curve, and (3): narrow solid line / curve, the values are:

r_1 = 3.1 μm (1)
= 3.5 μm (2)
= 3.4 μm (3)
r_2 = 6.8 μm (1)
= 7.0 μm (2)
= 7.6 μm (3)
r_3 = 9.2 μm (1)
= 11.2 μm (2)
= 13.64 μm (3)
r_4 = Cladding radius.

Further, the refractive index of each layer based on the refractive index n_4 of the outermost layer (quartz) are:

Δ_1= 1.1% (1)
= 1.0% (2)

= 1.02% (3)
Δ_2 = -0.3% (1)
= -0.2% (2)
= -0.1% (3)
Δ_3 = 0.2% (1)
= 0.21% (2)
= 0.22% (3).

The main elements in this case are as shown in Table 1 [sic].

Theoretical cut-off wavelength	① 1.17 μm ② 2.16 μm ③ 3.09 μm
Mode field diameter	① 5.6 μm (1.3 μm) 7.1 μm (1.55 μm) ② 6.2 μm (1.3 μm) 8.1 μm (1.55 μm) ③ 6.4 μm (1.3 μm) 8.4 μm (1.55 μm)
Loss due to curving : (2cm R) at 1.55 μm	① 0.2 dB/m ② 1.3×10^{-3} dB/m ③ 6.4×10^{-3} dB/m
Light loss at 1.55 μm	① 0.27 dB/km ② 0.24 dB/km ③ 0.22 dB/km

[Table 2]
Theoretical cut-off wavelength
Mode field diameter
Loss due to curving
Light loss

One example of wavelength dispersion of a single mode fiber with a broad wavelength range and low dispersion in this embodiment is as shown in Figure 6. It is considerably better than the dispersion shown by conventional single mode fibers or W-type single mode fibers.

(Third Embodiment)

Figure 7 shows yet another embodiment of the present invention and concerns 1.3 μm to 1.55 μm band. The same keys are used for the same portions as in Figure 1.

This embodiment shows a case in which the dimension and refractive index of each layer are varied using six different values as shown in Figure 7. When each value is indicated as (1): three-fold dotted line / curve, (2): two-fold dotted line / curve, (3): dotted line / curve, (4): solid line / curve, (5): dotted line / curve, and (6): long dotted line / curve, the values are:

r_1 = 5.2 μm (1)
= 4.7 μm (2)
= 4.3 μm (3)
= 4.0 μm (4)
= 3.7 μm (5)
= 3.5 μm (6)
r_2 = 7.2 μm (1)-(6)
r_3 = 11.2 μm (1)-(6)
r_4 = Cladding radius.

Further, the refractive index of each layer based on the refractive index n_4 of the outermost layer (quartz) are:

Δ_1= 0.624% (1)
= 0.677% (2)
= 0.730% (3)
= 0.783% (4)
= 0.836% (5)
= 0.890% (6)
Δ_2= -0.25% (1)-(6)
Δ_3= 0.2% (1)-(6).

The main elements in this case are as shown in Table 3.

Mode field diameter	① 8.1μm (1.3 μm) 11.1μm (1.55μm) ② 7.6μm (1.3 μm) 10.5μm (1.55μm) ③ 7.2μm (1.3 μm) 10.1μm (1.55μm) ④ 6.9μm (1.3 μm) 9.6μm (1.55μm) ⑤ 6.7μm (1.3 μm) 9.3μm (1.55μm) ⑥ 6.5μm (1.3 μm) 8.9μm (1.55μm)
Loss due to curving (2cm R) at 1.55μm	① 0.7dB/m ② 0.7dB/m ③ 0.6dB/m ④ 0.4dB/m ⑤ 0.5dB/m ⑥ 0.2dB/m
Light loss : (2 cm R)	① 0.56 dB/km (1.3 μm) 0.27 dB/km (1.55μm) ② 0.50 dB/km (1.3 μm) 0.26 dB/km (1.55μm) ③ 0.40 dB/km (1.3 μm) 0.22 dB/km (1.55μm) ④ 0.60 dB/km (1.3 μm) 0.34 dB/km (1.55μm) ⑤ 0.55 dB/km (1.3 μm) 0.32 dB/km (1.55μm) ⑥ 0.62 dB/km (1.3 μm) 0.35 dB/km (1.55μm)

[Table 3]
Mode field diameter
Loss due to curving
Light loss

One example of wavelength dispersion of the single mode fiber with a broad wavelength range and low dispersion in this embodiment is as shown in Figure 8. It is considerably better than the dispersion shown by conventional single mode fibers or W-type single mode fibers.

In each of the abovementioned embodiments, in the portion of the innermost layer 1 connected to the second layer 2, fluctuation in refractive index in the longitudinal direction of the optical fiber did not occur since incomplete structure at the time of production was prevented, and the light loss did not increase. Moreover, even if the refractive index of the third layer was increased, the wavelength dispersion did not worsen.

Furthermore, in each of the abovementioned embodiments, the refractive index decreased in the center of the innermost layer 1. This is because impurities were lost when heated during co-plus production of the manufactured by the MCVD method. However, this does not have any impact on the effects of the present invention.

[Effects of the Invention]

As described above, the single mode fiber with a broad wavelength range and low dispersion according to the present invention has the following effects, and is considerably better than [the fiber] manufactured using conventional technology:

1. Loss due to curving is small.
2. It is applicable to a broad wavelength range (1.2 μm -1.7 μm).
3. Increase of loss and worsening of wavelength dispersion due to the structure are prevented.

[Brief Description of the Drawings]

Figure 1 shows the basic construction of the present invention.
Figure 2 shows the characteristics of single mode fiber with a broad wavelength range and low dispersion according to the present invention.
Figure 3 shows one embodiment of the present invention.
Figure 4 shows the wavelength dispersion of the embodiment shown in Figure 3.
Figure 5 shows another embodiment of the present invention.
Figure 6 shows the wavelength dispersion in the embodiment in Figure 5.
Figure 7 shows yet another embodiment of the present invention.
Figure 8 shows the wavelength dispersion in the embodiment in Figure 7.
Figure 9 shows the construction of W-type single mode fiber.
Figure 10 shows example characteristics of W-type single mode fiber.
Figure 11 shows the construction of conventional single mode fiber with a broad wavelength range and low dispersion.
Figure 12 shows example characteristics of conventional single mode fiber with a broad wavelength range and low dispersion.

1: Innermost layer
2: Second layer
3: Third layer
4: Outermost layer

[keys to the figures]
Figure 1. Basic construction of the present invention
1: Innermost layer

2: Second layer
3: Third layer
4: Outermost layer

Figure 2. Characteristics of single mode fiber with a broad wavelength range and low dispersion according to the present invention
(a) X axis: Wavelength λ
Y axis: Delay τ
(b) X axis: Wavelength λ
Y axis: Wavelength dispersion m

Figure 3. One embodiment of the present invention
1: Innermost layer
2: Second layer
3: Third layer
4: Outermost layer
X axis: Radius
Y axis: Specific refractive index difference

Figure 4. Wavelength dispersion of the embodiment shown in Figure 3
X axis: Wavelength
Y axis: Wavelength dispersion

Figure 5. Another embodiment of the present invention
1: Innermost layer
2: Second layer
3: Third layer
4: Outermost layer
X axis: Radius
Y axis: Specific refractive index difference

Figure 6. Wavelength dispersion of the embodiment shown in Figure 3
X axis: Wavelength
Y axis: Wavelength dispersion

Figure 7. Yet another embodiment of the present invention
1: Innermost layer
2: Second layer
3: Third layer
4: Outermost layer
X axis: Radius
Y axis: Specific refractive index difference

Figure 8 Wavelength dispersion in the embodiment in Figure 7
X axis: Wavelength
Y axis: Wavelength dispersion

Figure 9 Construction of W-type single mode fiber

11: Core
12: Cladding
13: Middle layer

Figure 10 Example characteristics of the W-type single mode fiber
(a) X axis: Wavelength λ
Y axis: Delay τ
(b) X axis: Wavelength λ
Y axis: Wavelength dispersion m

Figure 11 Construction of conventional single mode fiber with a broad wavelength range and low dispersion
1: Innermost layer
2: Second layer
3: Third layer
4: Outermost layer

Figure 12 Example characteristics of conventional single mode fiber with a broad wavelength range and low dispersion.
(a) X axis: Wavelength λ
Y axis: Delay τ
(b) X axis: Wavelength λ
Y axis: Wavelength dispersion m

1: Innermost layer
2: Second layer
3: Third layer
4: Outermost layer

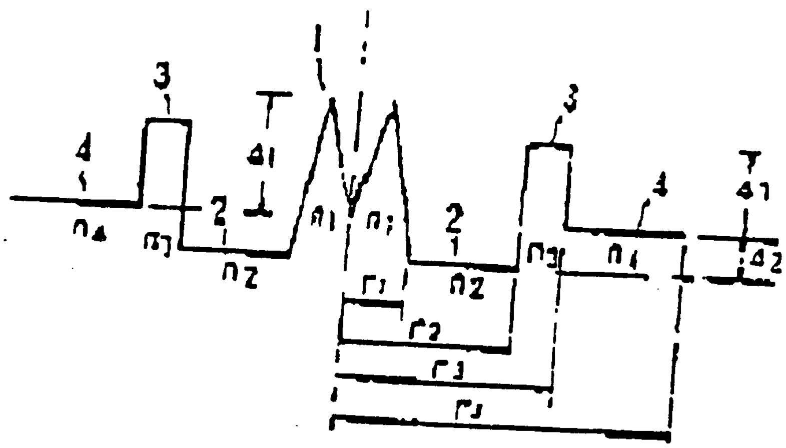


Figure 1. Basic construction of the present invention

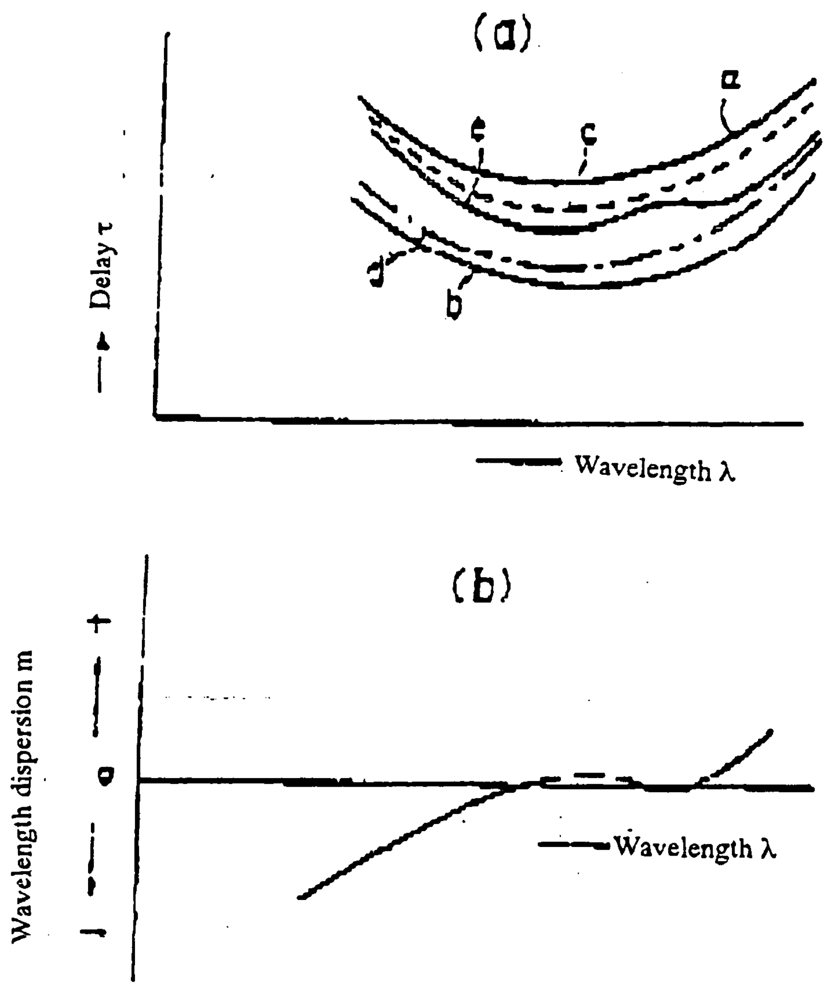


Figure 2. Characteristics of single mode fiber with a broad wavelength range and low dispersion according to the present invention

1: Innermost layer
2: Second layer
3: Third layer
4: Outermost layer

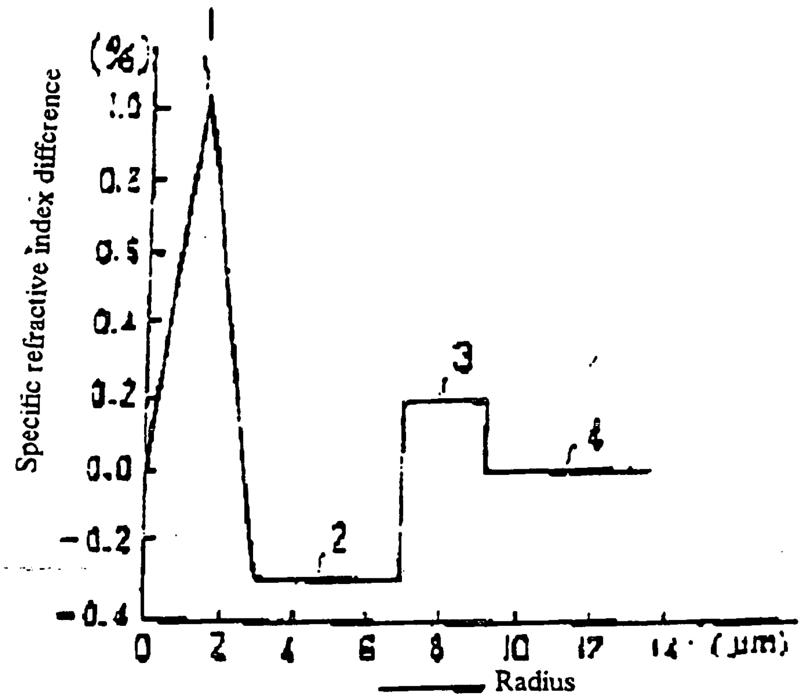


Figure 3. One embodiment of the present invention

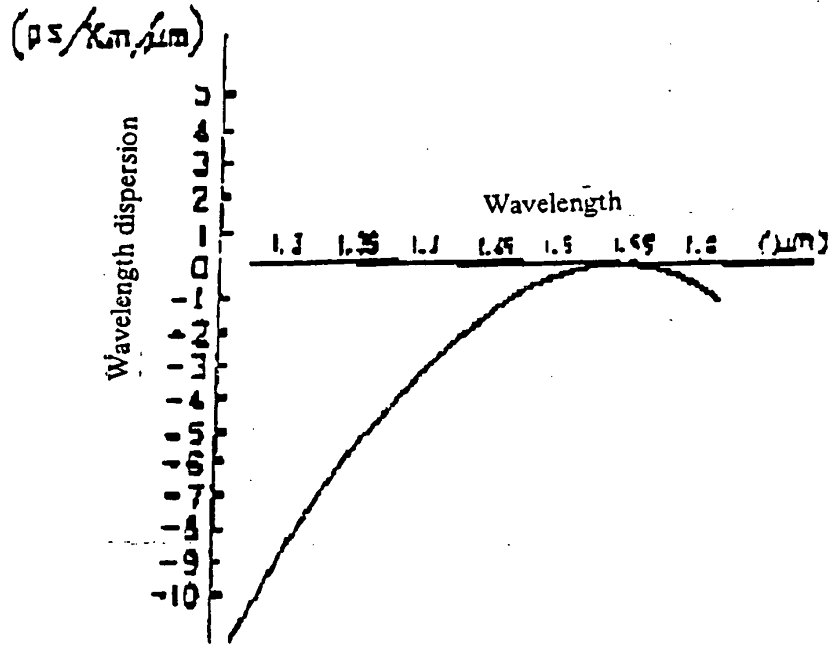


Figure 4. Wavelength dispersion of the embodiment shown in Figure 3

1: Innermost layer
2: Second layer
3: Third layer
4: Outermost layer

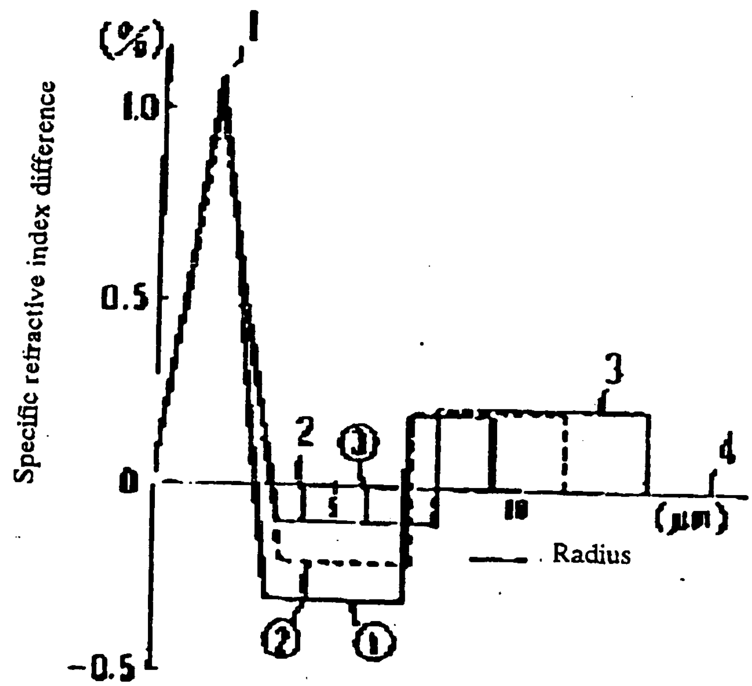


Figure 5. Another embodiment of the present invention

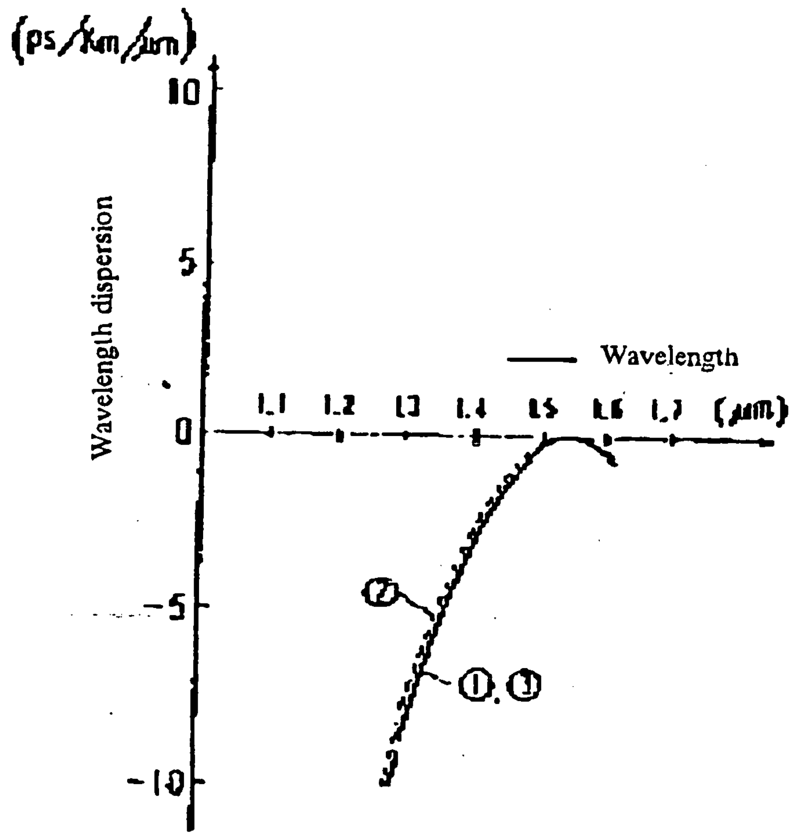
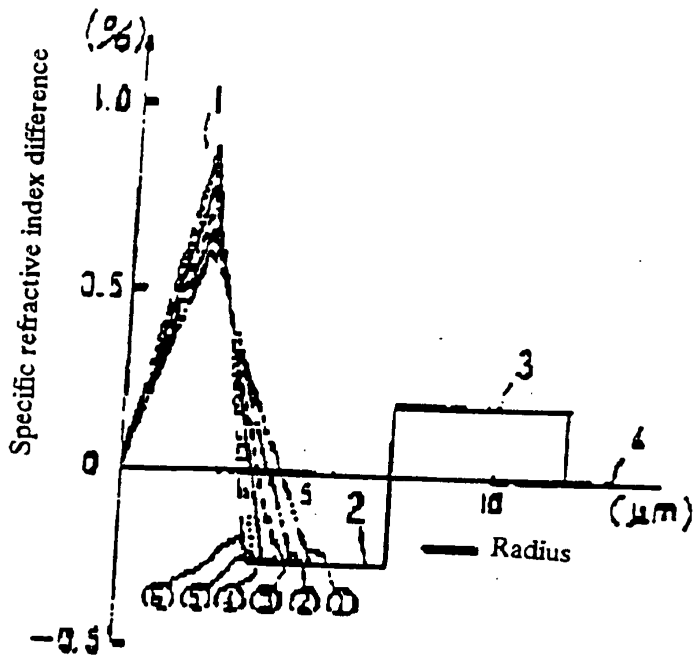


Figure 6. Wavelength dispersion of the embodiment shown in Figure 3



1: Innermost layer
2: Second layer
3: Third layer
4: Outermost layer

Figure 7. Yet another embodiment of the present invention

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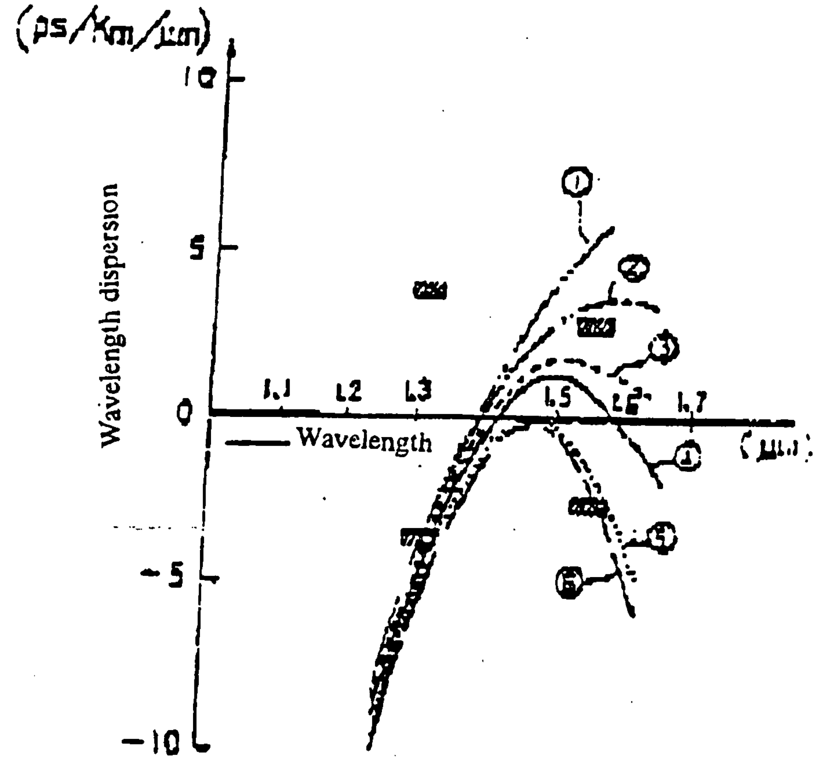

Figure 8 Wavelength dispersion in the embodiment in Figure 7

11: Core
12: Cladding
13: Middle layer

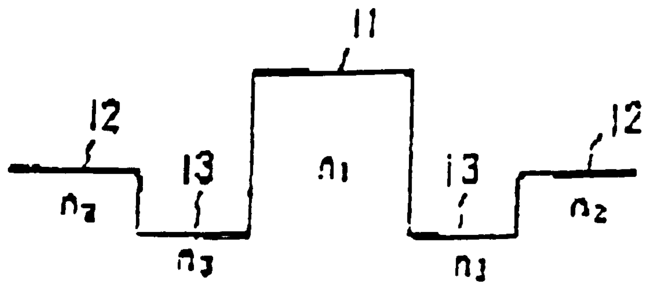

Figure 9 Construction of W-type single mode fiber

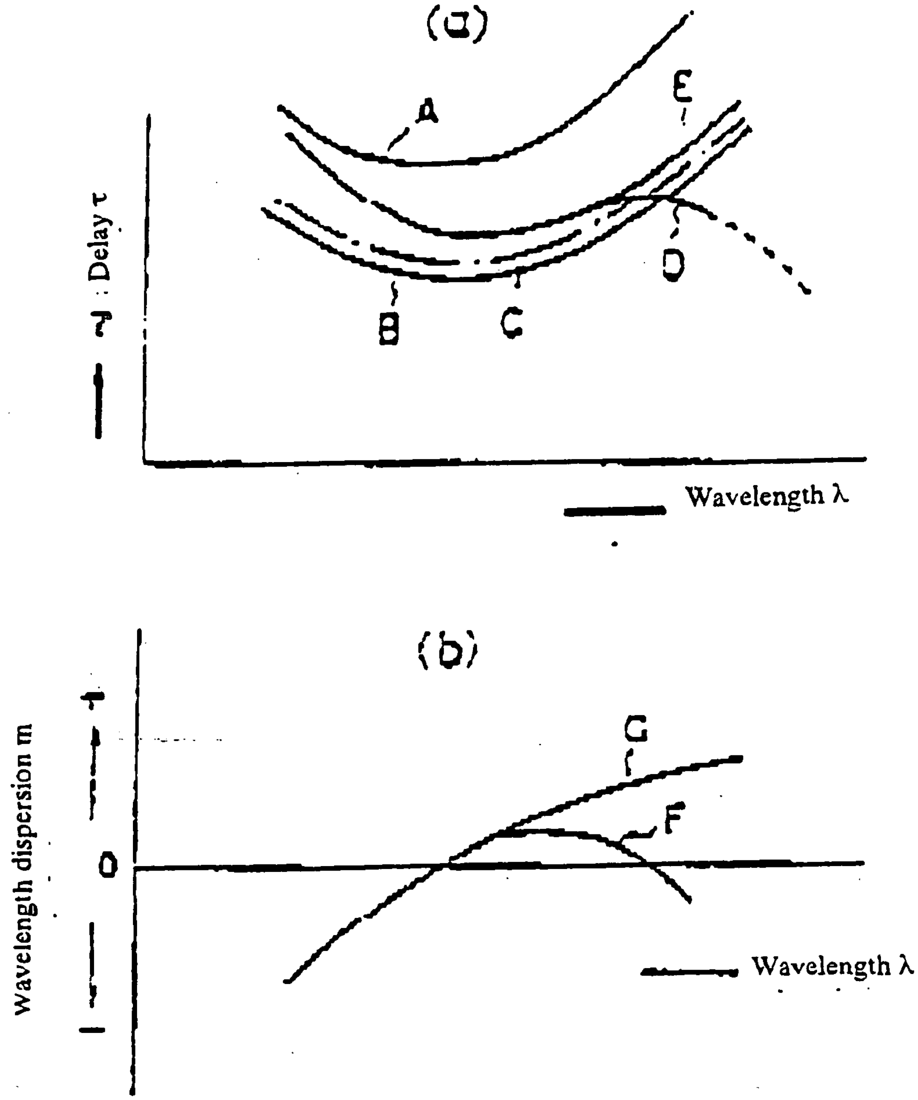

Figure 10 characteristics of the W-type single mode fiber

1: Innermost layer
2: Second layer
3: Third layer
4: Outermost layer

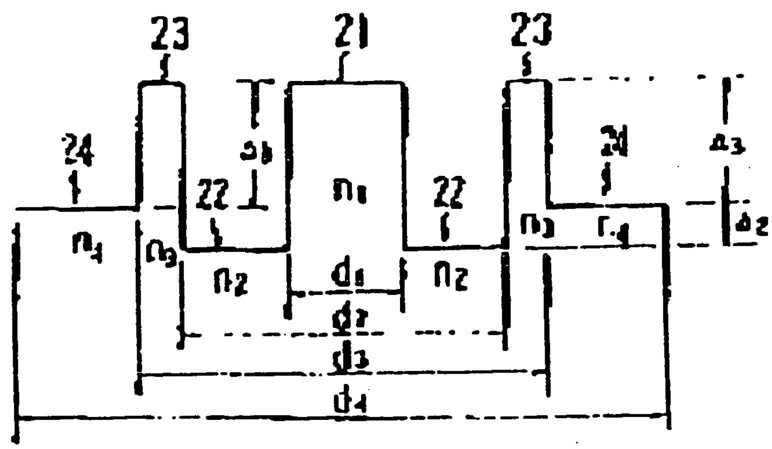

Figure 11 Construction of conventional single mode fiber with a broad wavelength range and low dispersion

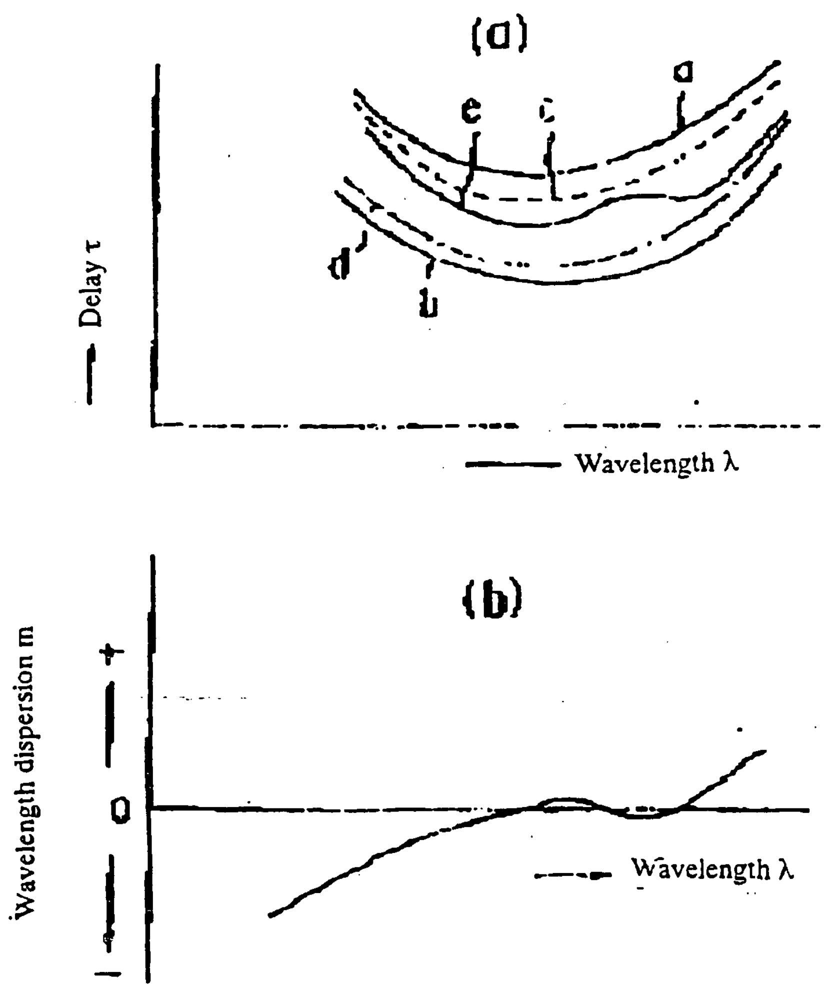

Figure 12 . characteristics of conventional single mode fiber with a broad wavelength range and low dispersion.